# EFFECTS OF INFILTRATION FUNCTION ON SIMULATED LEACHING DISTRIBUTIONS IN THE IMPERIAL VALLEY, CALIFORNIA


Prepared By

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### *ANTECENDENTS*

Infiltration is the most crucial factor affecting surface irrigation. This single parameter essentially controls the amount of water entering the soil as well as the advance and recession rates of the overland flow. Nor is any other factor as difficult to determine or predict with reliability and accuracy. Not surprisingly therefore, infiltration has been given a great deal of theoretical attention.

Historically, infiltration in borders and basins used the Kostiakov Equation:[2]

$$\mathbf{Z} = \mathbf{k}\boldsymbol{\tau}^{\mathbf{a}} \tag{1}$$

where **Z** is the cumulative infiltration in $m^3/m/m$, $\tau$ is the "intake opportunity time" in minutes, and the **k** and **a** coefficients are empirical. The duration of the water application for these systems is usually short enough that the intake rate, $I=\partial Z/\partial\tau$ , will not underestimate infiltration. In furrow irrigation systems, however, this problem is common and some modelers adopted the Kostiakov-Lewis Equation[3], which solves the long-term infiltration rate problem by adding a term for the final or "basic" intake rate:

$$Z = k\tau^a + f_o\tau \tag{2}$$

where $\mathbf{f_o}$ is the "basic intake rate" in $m^3/m/m/min$.

In recent studies, Eq. 2 has been expanded to include a combined term for both cracking and depression storage:[4]

$$Z = k\tau^a + f_o\tau + c \tag{3}$$

where **c** is the amount of water applied to the soil through cracks or from depression storage following irrigation in $m^3/m/m$. One can observe that if $\mathbf{f_o}$ is set to zero, Eq. 3 has the same form as the NRCS infiltration equation[5]:

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[1] Utah Registration No. 152758-2202.

[2] Kostiakov, A. V. 1932. On the dynamics of the coefficient of water-percolation in soils and on the necessity for studying it from a dynamics point of view for purposes of amelioration. Trans. Sixth Comm. Int. Soc. Soil Sci., Part A, pp. 17-21.

[3] Walker, Wynn R. and Gaylord V. Skogerboe. 1987. ***Surface Irrigation: Theory and Practice***. Prentice-Hall Inc., Englewood Cliffs, NJ. 386pp.

[4] Strelkoff, T.S., Clemmens, A.J., and Bautista, E. "Field-parameter estimation for surface irrigation management and design." *Water Management 2000, ASCE Conference, Ft.Collins, CO, June 21-24, 2000.* WCLPUB No. – 2234.

[5] US Department of Agriculture, Natural Resource and Conservation Service. National Engineering Handbook, 1974. Section 15, Chapter 4, *Border Irrigation.* US Government Printing Office, Washington, DC.




[1] Utah Registration No. 152758-2202.

[2] Kostiakov, A. V. 1932. On the dynamics of the coefficient of water-percolation in soils and on the necessity for studying it from a dynamics point of view for purposes of amelioration. Trans. Sixth Comm. Int. Soc. Soil Sci., Part A, pp. 17-21.

[3] Walker, Wynn R. and Gaylord V. Skogerboe. 1987. ***Surface Irrigation: Theory and Practice***. Prentice-Hall Inc., Englewood Cliffs, NJ. 386pp.

[4] Strelkoff, T.S., Clemmens, A.J., and Bautista, E. "Field-parameter estimation for surface irrigation management and design." *Water Management 2000, ASCE Conference, Ft.Collins, CO, June 21-24, 2000.* WCLPUB No. – 2234.

[5] US Department of Agriculture, Natural Resource and Conservation Service. National Engineering Handbook, 1974. Section 15, Chapter 4, *Border Irrigation.* US Government Printing Office, Washington, DC.

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[1] Utah Registration No. 152758-2202.

$$Z = k\tau^a + c \quad (4)$$

Most simulation models in use today employ these infiltration functions in one or all of the forms exhibited by Eqs. 1 -- 4. For example, the ***SIRMOD III*** program developed by the author[6] uses Eq. 3 so that each of the others can be defined by setting various parameters to zero. The ***SRFR*** program developed by the USDA also uses this form of infiltration function.[7]

Several scientific attempts have been made to describe the values of $a$, $k$, and/or $f_o$ as functions of soil type. Among the first of these was the USDA (1974), followed by an effort at Utah State University[8]. Later Merriam and Clemmens (1985) visited the subject[9]. In 1997, new sets of values were developed as part of the development of the ***SIRMOD III*** software to include both continuous and surge flow and for both first and later irrigations. These are included in the software as a function of the NRCS intake family number.

There are no currently scientifically developed recommendations available for the c-value even though some studies have studied the impact of soil salinity on crack formation.[10] [11] However, in the 2002 NRCE "Water Use Report" nine of the ten evaluations of fields served by IID[12] included values for both $c$ and $f_o$. How these values were arrived at is unclear and such derivation was not available in the NRCE Report.

The ***SIRMOD III*** software was used to simulate the NRCE data culminating in a report based on the Kostiakov-Lewis function ($c$=0).[13] Included in this earlier report were a series of simulations of leaching distributions with and without improved field designs and modified management practices. Earlier and independent reports of scientific research involving field evaluations and lysimeter studies indicated that the basic infiltration rate, $f_o$, was substantially lower that the values reported by NRCE. The ***SIRMOD III*** calibrations arrived at the same conclusion with basic infiltration rates less than one-third the values reported by NRCE. Further, in the initial ***SIRMOD III*** calibrations, the cracking value, $c$, was set to zero. In this report, the results of further calibration of the ***SIRMOD III*** software using the Kostiakov function, Eq. 1, and the Kostiakov-Crack function, Eq. 4, are presented to indicate what the choice of equation might have on leaching distributions.

## *METHODOLOGY AND SCOPE*

Since the NRCE data does not include advance rates, the software was calibrated to reported values of inflow rate, tailwater volume, set times, total advance times, and deep percolation volumes. The advance trajectory was assumed to be nearly linear based on NRCE's

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[6] Walker, W. R. 2003. "***SIRMOD III*** – Surface Irrigation Simulation, Evaluation, and Design. Guide and Technical Documentation. Biological and Irrigation Engineering. Utah State University, Logan, Utah. 146p

[7] Strelkoff, T.S., Clemmens, A.J., and Schmidt, B.V. 1998. SRFR v. 3.31. Computer Program for Simulating Flow in Surface Irrigation: Furrows-Basins-Borders, available upon request from the U.S. Water Conservation Lab., USDA/ARS, 4331 E. Broadway, Phoenix, AZ 85040. Version 4.06 is now available.

[8] Walker, W. R. 1989. Guidelines for designing and evaluating surface irrigation systems. FAO Irrigation and Drainage Paper 45, Food and Agriculture Organization of the United Nations, Rome, Italy. 137p.

[9] Merriam, J.L. and Clemmens, A.J. 1985. Time rated infiltrated depth families. p. 67-74 in Development and Management Aspects of Irrigation and Drainage, Spec. Conf. Proc., Irrig. and Drain. Div., ASCE, San Antonio, TX, July.

[10] Lima, L. A. and M. E. Grismer. 1992. Soil Cracking Morphology and Soil Salinity. Soil Science (153)2:149-153.

[11] Grismer, M. E. 1992. Cracks in Irrigated Clay Soil May Allow Some Drainage. California Agriculture (46)5:9-11.

[12] Natural Resources Consulting Engineers, Inc. 2002. Assessment of Imperial Irrigation District's Water Use. Report and Appendices. March.

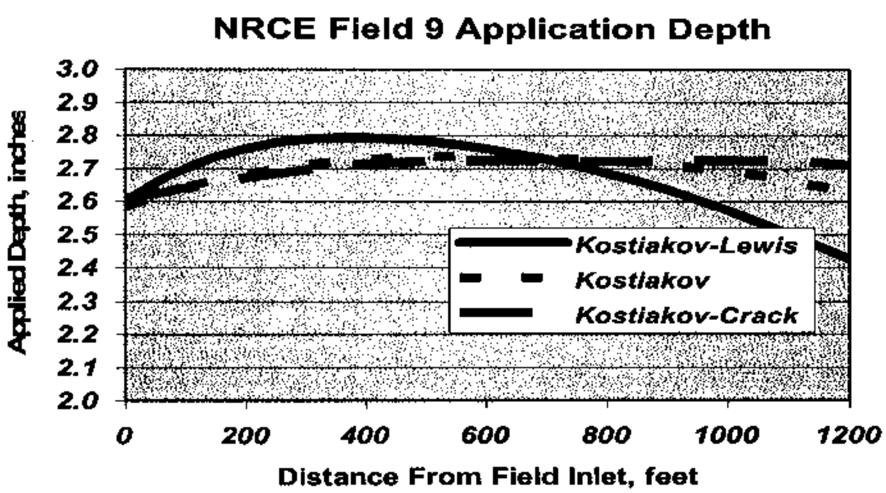
[13] Walker, W. R. 2003. Improving Surface Irrigation Designs and Management Practices in the Imperial Valley, California. Internal Document, Metropolitan Water District of Southern California.

observations that advance rates were constant. (See also Grismer and Tod, 1994[14] )This was accomplished for each of three infiltration functions, Kostiakov, Kostiakov-Lewis, and Kostiakov-Crack, and for each of the NRCE fields 1 – 9. Simplification of the process was made by assuming the value of the exponent $a$ in Eqs. 1 – 4 would be the same for each function and based on soil type. Further, the basic intake rate, $f_o$, was assumed to be 0.1 inch/hr (except for Field 4 which used a 0.025 in/hr basic intake rate) and the cracking value, $c$, was set to 1 inch. This value of the basic intake rate is consistent with the soils in the NRCE study. It should be noted that NRCE did not indicate a $c$-value for some of the soils as cracking was not apparent. Including it in this analysis is for the purpose of comparing functional forms rather than addressing the specific characteristics of any of the NRCE fields. Values of field slope and length, soil moisture depletion, inflow, and set times were the same as NRCE reported in all cases.

Once the calibrations had been made, the distribution of deep percolation was computed at each computation grid point in the software's analytical procedure. The leaching fraction was then computed as:

$$LF_i = \frac{dp_i}{id_i} * 100 \tag{5}$$

in which $LR_i$ is the point-specific leaching fraction at the i$^{th}$ computational grid point in %, $dp_i$ is the deep percolation in inches at the i$^{th}$ point, and $id_i$ is the infiltrated depth in inches at the i$^{th}$ point. The value of deep percolation was computed using the NRCE values of soil moisture depletion. As noted in the previous calibrations of the software, these reported values are estimates based on what appear to be three measurements in each field and might actually vary by as much as a half-inch. As one example, Figure 1 shows the applied depths simulated on NRCE Field 9 from which different required depths can be drawn horizontally to determine leaching under other soil moisture depletions. If the actual soil moisture deficit was 2.5 inches rather than the 2.6 inches reported, the volume of leaching would increase but its distribution over the field would be the same.




[14] Grismer, M. E. and I. C. Tod. 1994. Field Procedure Helps Calculate Irriation Time for Cracking Clay Soils. California Agriculture (48)4:33-36/

## *RESULTS AND DISCUSSION*

The results of the infiltration function comparison are shown below for the nine NRCE fields in Appendix I. Before examining these three alternative infiltration functions it is perhaps helpful to illustrate their basic differences. Figure 2 below plots each function over the averagbe duration of the irrigation for NRCE Field 3. Keep in mind that using any of the three in the hydraulic model will result in the same simulated values of advance time, tailwater volume and deep percolation volume. The reason each function produces the same result is that they each compute the same accumulated infiltration. However, because the curves take different paths to this point, the distribution of leaching and the shape of the tailwater hydrograph will be different.

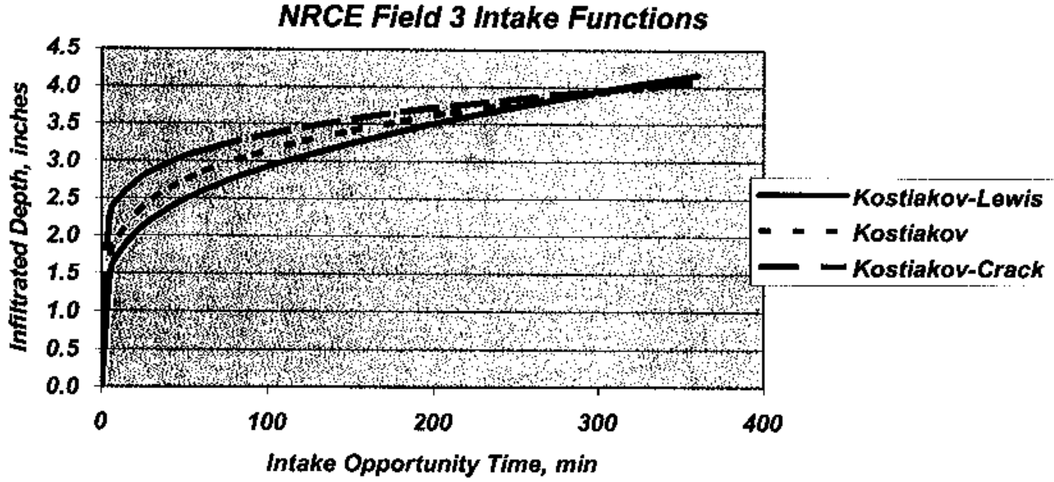



*Figure 2*

The Kostiakov-Lewis creates more non-linearity in both the advance and recession trajectories because it is time dependent in both of its terms. Consequently, this function consistently distributes applied water in a more non-uniform manner than the Kostiakov or Kostiakov-Crack functions. As noted, there is generally less leaching at the ends of the field than in the center – this is an artifact of the impact this equation has on recession. In many border irrigation situations the upper end of the field receives less water than the lower end because recession is a much slower process than it is in furrows.

The Kostiakov and Kostiakov-Branch behave nearly the same and appear to be interchangeable in terms of the conditions NRCE monitored. The Kostiakov-Branch is designed to account for substantial infiltration occurring as part of crack filling whereas the Kostiakov lends credence to the postulate that cracking simply increases the wetter perimeter so infiltration is increased while they are open.

In terms of leaching over a field, both the Kostiakov and Kostiakov-Crack reduce the variance over the field as compared to the Kostiakov-Lewis, but the variability is still substantial and would need to be mitigated in pre-plant and emergence irrigations to avoid salt buildup at one end or the other in these type of fields.

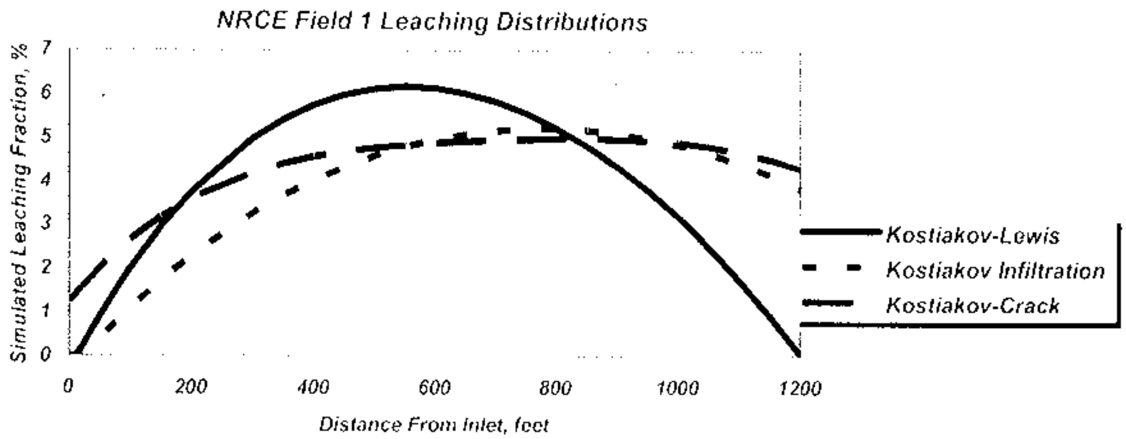
In the absence of actual infiltrometer measurement, the only reliable way to distinguish which form of the equations should be used in extended simulations is to examine the secondary consequences of functional form relative to the shape of the tailwater hydrograph, and in the case of the Imperial Valley studies, the salinity distributions that NRCE measured. Tailwater hydrographs were not published for NRCE Fields 3 and 9 which demonstrate the most fundamental differences in the infiltration equations. The variation in salinity measurements is too great to draw any certain conclusions, but one would tend to judge that the profiles predicted by the Kostiakov-Lewis function are not manifest to the degree one would expect.

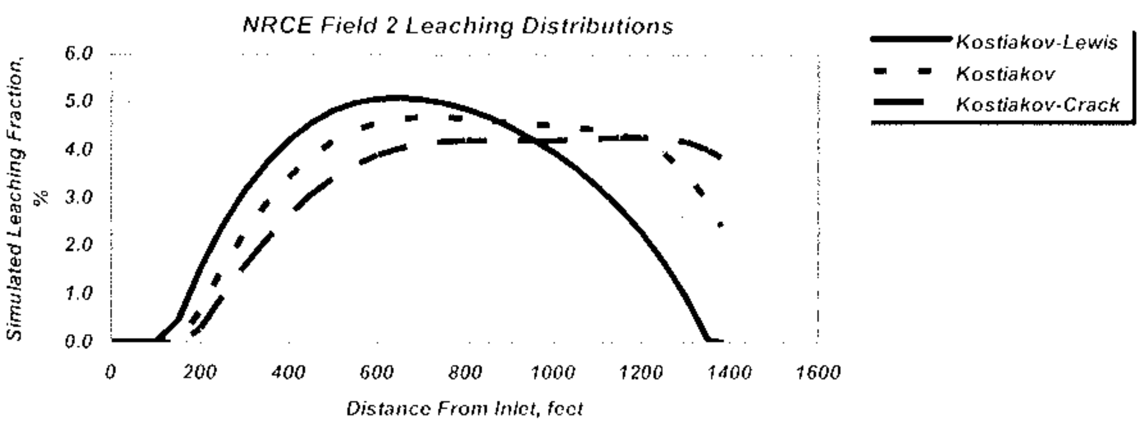
### *CONCLUSIONS*

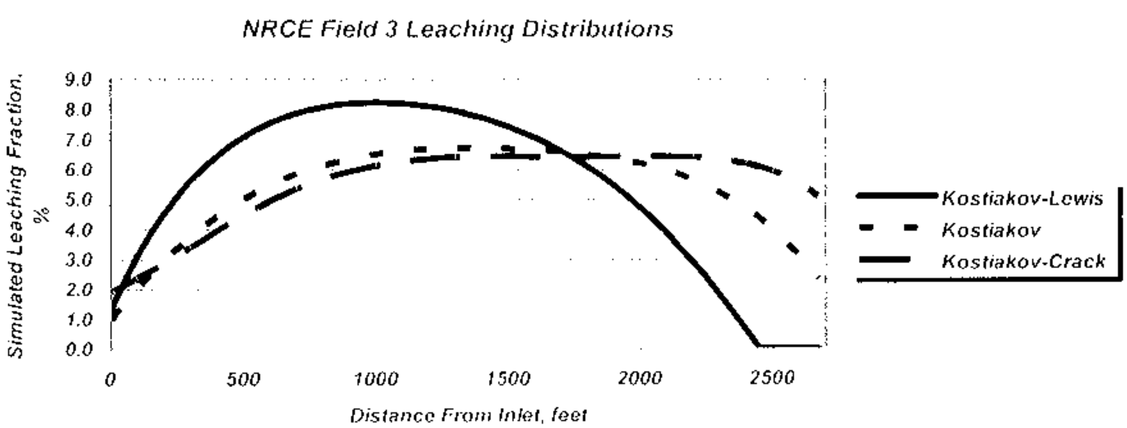
All of the NRCE fields have relatively low intake characteristics and most exhibit substantial cracking when dry. A question arises concerning what type of infiltration function should be used in simulating these soils in the context of a surface irrigation hydraulic model. Based on extensive examination of NRCE data, it appears the most likely candidates would be the Kostiakov and Kostiakov-Crack forms of the extended Kostiakov relationship. Even with a very low basic intake rate of 0.1 in/hr, the Kostiakov-Lewis function leads to predictions of leaching distributions that cannot be verified by the NRCE measurements of salinity in the fields they monitored. Other sources of information from research studies suggest that even a basic intake rate of 0.1 in/hr may be too high for the heavier soils in the area. The one other source of information from the NRCE tests, the tailwater hydrographs, do not appear to suggest one method over another except that the sharpe spiked nature of several hydrographs are more suggestive of Kostiakov and Kostiakov-Crack than the Kostiakov-Lewis function. It should be noted however that among the tailwater hydrographs IID has provided MWD, there are a substantial number that are more suggestive of the reverse, particularly for the lighter, furrow irrigated soil conditions.

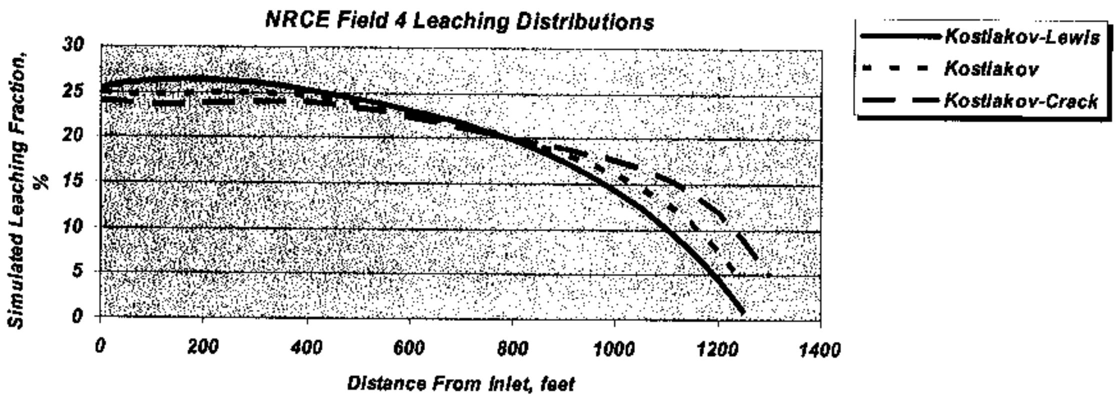
## APPENDIX I

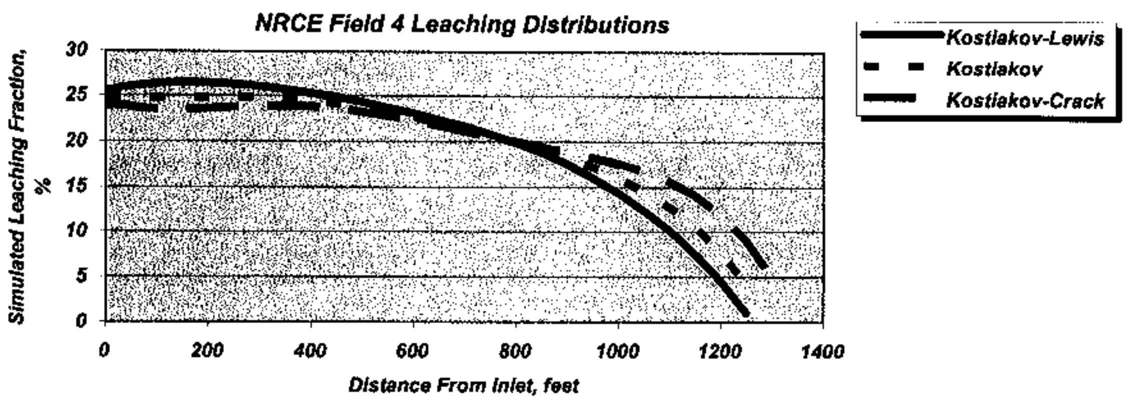
## SIMULATED LEACHING DISTRIBUTIONS ON NRCE FIELDS 1 – 9 USING KOSTIAKOV, KOSTIAKOV-LEWIS, AND KOSTIAKOV-CRACK INTAKE FUNCTIONS

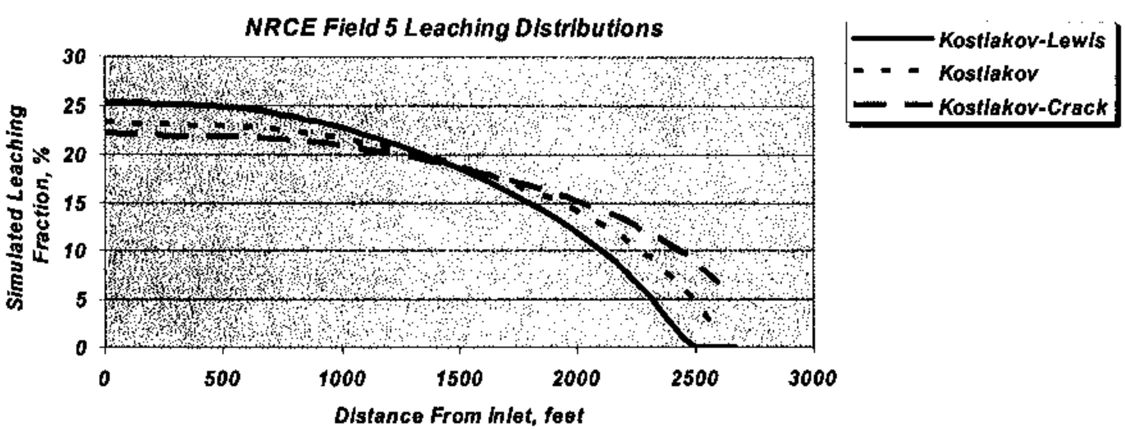


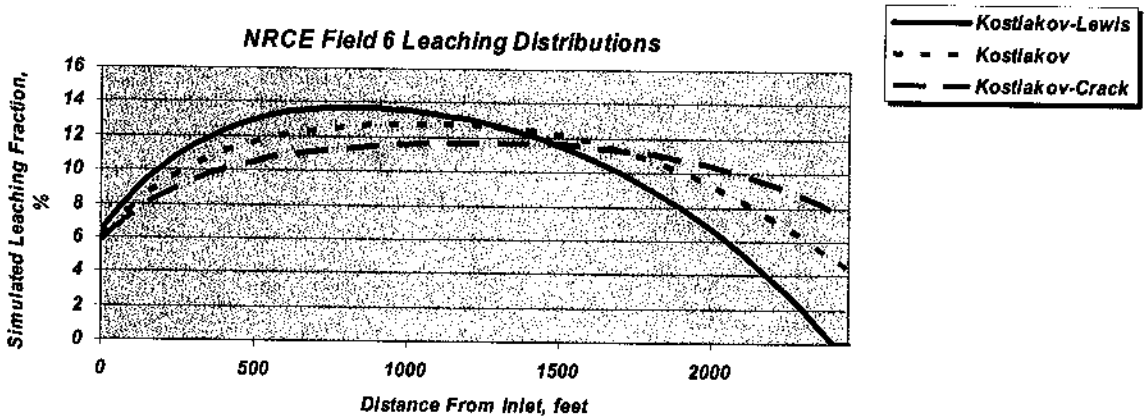



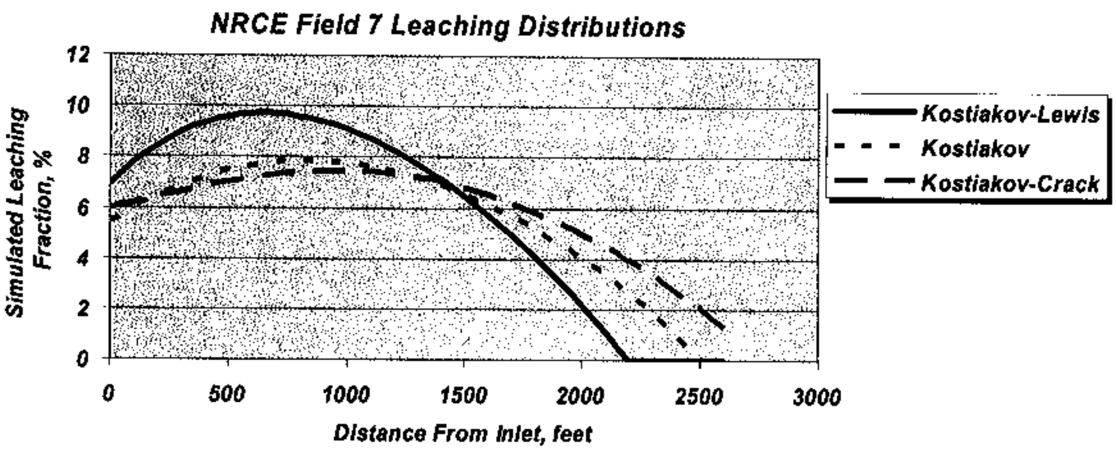



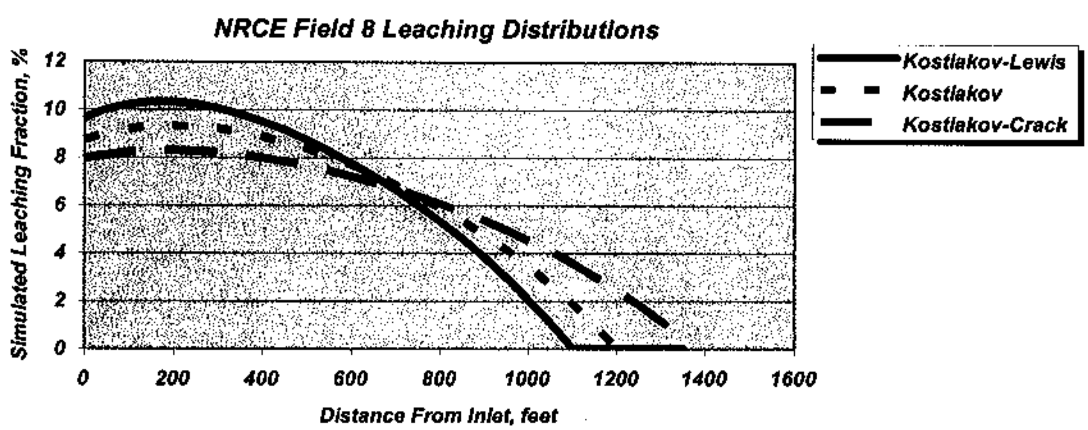

NRCE Field 4 Leaching Distributions
Simulated Leaching Fraction, %
Distance From Inlet, feet
Kostiakov-Lewis
Kostiakov
Kostiakov-Crack
0
5
10
15
20
25
30
0
200
400
600
800
1000
1200
1400

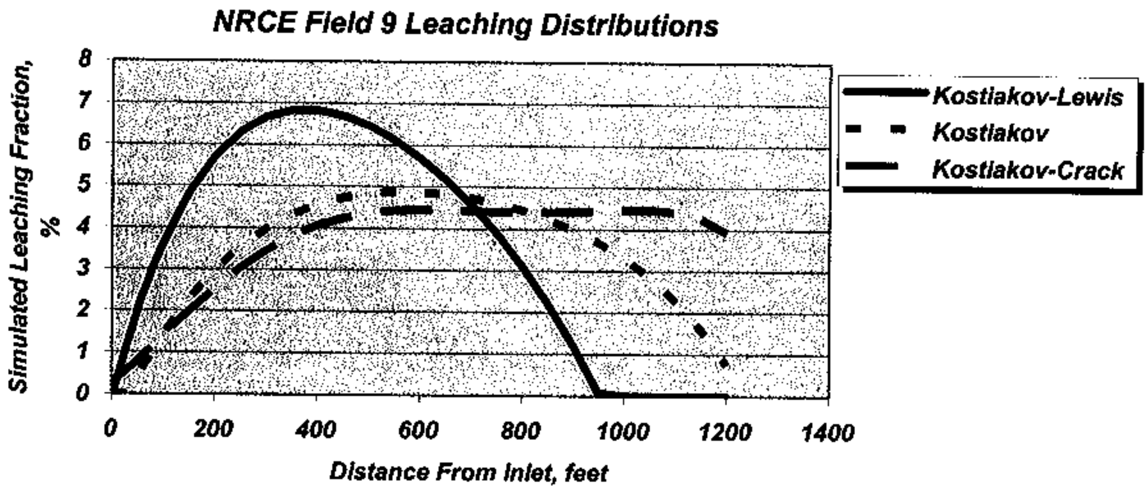

NRCE Field 4 Leaching Distributions
Simulated Leaching Fraction, %
Distance From Inlet, feet
Kostiakov-Lewis
Kostiakov
Kostiakov-Crack
0
5
10
15
20
25
30
0
200
400
600
800
1000
1200
1400


NRCE Field 5 Leaching Distributions
Simulated Leaching Fraction, %
Distance From Inlet, feet
Kostiakov-Lewis
Kostiakov
Kostiakov-Crack
0
5
10
15
20
25
30
0
500
1000
1500
2000
2500
3000


NRCE Field 6 Leaching Distributions
Kostlakov-Lewis
Kostlakov
Kostlakov-Crack
Simulated Leaching Fraction, %
16
14
12
10
8
6
4
2
0
0
500
1000
1500
2000
Distance From Inlet, feet


NRCE Field 7 Leaching Distributions
Kostiakov-Lewis
Kostiakov
Kostiakov-Crack
Simulated Leaching Fraction, %
12
10
8
6
4
2
0
0
500
1000
1500
2000
2500
3000
Distance From Inlet, feet


NRCE Field 8 Leaching Distributions
Kostlakov-Lewis
Kostlakov
Kostlakov-Crack
Simulated Leaching Fraction, %
12
10
8
6
4
2
0
0
200
400
600
800
1000
1200
1400
1600
Distance From Inlet, feet


NRCE Field 9 Leaching Distributions
Simulated Leaching Fraction, %
8
7
6
5
4
3
2
1
0
0
200
400
600
800
1000
1200
1400
Distance From Inlet, feet
Kostiakov-Lewis
Kostiakov
Kostiakov-Crack